DESIGN OF LOW-COST IMPACT REPORTING SYSTEM

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13. ABSTRACT (Maximum 200 Words)

Human form dummies may be used as targets in some types of training exercises. In order to assess performance on target, it may be necessary to know the time and location of all impacts upon the targets. A sparring dummy can provide a desirable target as well as house an impact reporting system.

A low-cost, self-contained impact reporting system has been designed within the form factor of a sparring dummy. The design goal of this system was to detect and report the location of every high-speed impact upon the target. The embedded system consisted of the sensors, interface circuitry, data acquisition hardware, power supply, and an embedded host processor with wireless communication to a central server.

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EXECUTIVE SUMMARY

A low-cost, self-contained system for wireless reporting of impacts was designed as an internal modification to a sparring dummy. Three designs were developed and tested, each using a different sensor: mechanical pushbutton switch, piezoelectric device, and Micro-ElectroMechanical System (MEMS) accelerometer. The mechanical switch-based system prototype was built and successfully tested. The piezoelectric and accelerometer systems were designed, and laboratory testing confirmed the feasibility of each approach.

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I. INTRODUCTION

Human form sparring dummies can be used as targets in training exercises. In order to assess performance on target, it may be necessary to know the time and location of all impacts upon the targets. An embedded impact detection and reporting system can be installed within a sparring dummy to perform that function.

A low-cost, embedded impact reporting system has been designed within the form factor of a sparring dummy, with the goal of detecting and reporting the location and time of every high-speed impact. The embedded system consisted of the sensors, interface circuitry, data acquisition hardware, power supply, and an embedded host processor with wireless communication to a central server.

Multiple targets may be arranged in a training scenario, and all report impact information to the central server, as shown in Figure 1. The server would collect, store, and analyze all impact reports. In addition, the server would provide the master clock to synchronize all embedded systems.
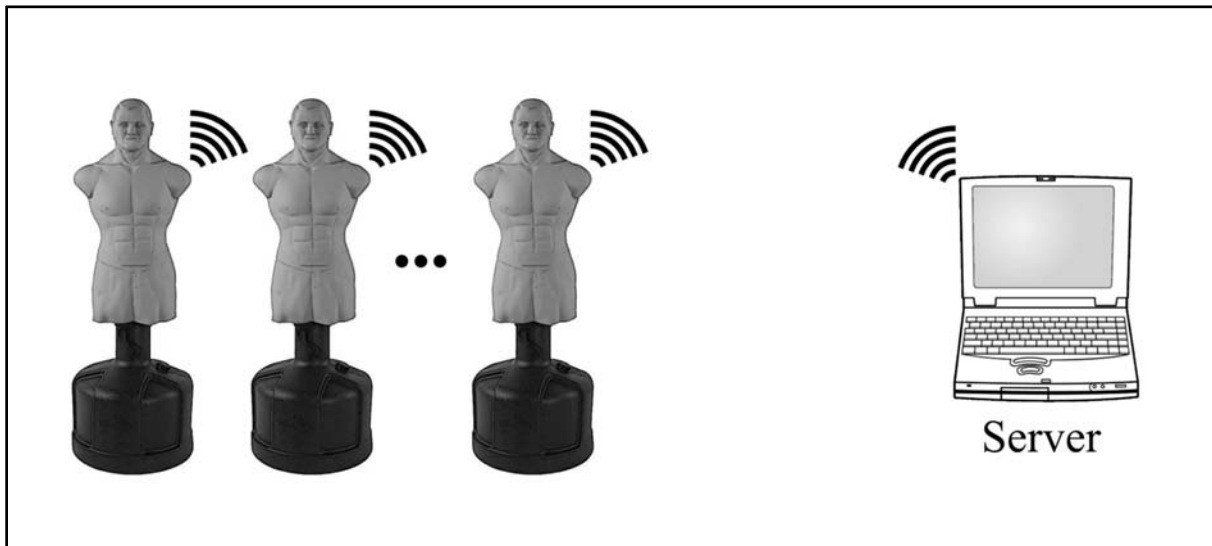
Figure 1. Impact Reporting System Concept

II. SYSTEM REQUIREMENTS

The functional requirements for the target impact reporting system are that it be self-powered and self-contained inside the dummy and report all impacts in near real time. All nominal collisions with the sparring dummy must be sensed in real time, and the location and time information communicated to the server in near real time. The system must not require external wired connections during operation.

The cost requirement limited each target to $1,000. The cost of the Century BOB XL sparring dummy was $320, leaving approximately $680 for the impact reporting system. No known Commercial Off-The-Shelf (COTS) system could accomplish this within the cost constraints. Therefore, a component level design was required.

During an exercise, a target may experience multiple hits possibly at or near the same point. The sensors must detect each impact, survive, and recover in time to report the next event. Initial tests estimated that the duration of an impact will be approximately 8 milliseconds. Therefore, all sensor data collection must be completed within this time frame.

The placement of multiple targets may be changed during an exercise, making external wiring connections problematic. Furthermore, there is no guarantee that time would permit recharging of all targets between exercises. Therefore, each embedded system must provide enough power to last through multiple exercises, and communications must be accomplished wirelessly.

III. DESIGN CONSIDERATIONS

A. Sensors

Because the impact reporting system must be self-contained, all sensors must be mounted inside of the sparring dummy. This limits the sensors to those which detect force or acceleration. The three candidate sensors tested were mechanical pushbutton switches, piezoelectric sensors, and Micro-ElectroMechanical System (MEMS) accelerometers, as shown in Figure 2.

| (a.) Mechanical Switch | (b.) Piezoelectric Sensor | (c.) MEMS Accelerometer |
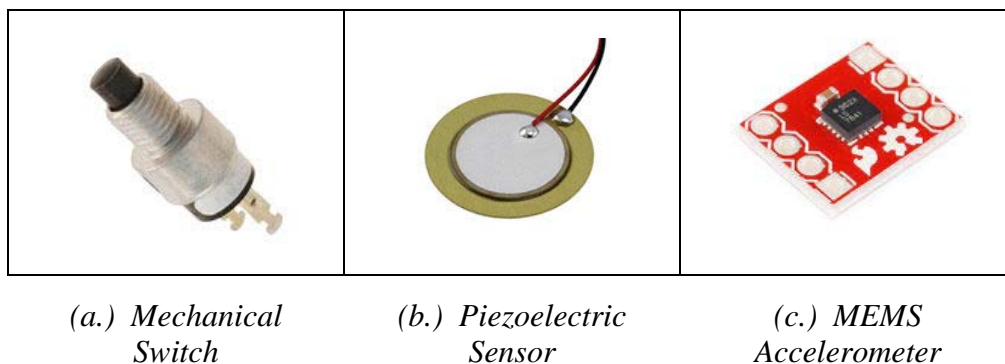
Figure 2. Candidate Sensors

An array of sensors could triangulate the point of impact, much like seismic detection. However, the material of the sparring dummy is absorbent, and thus may require a closely spaced array of sensors in order to ensure the necessary number of sensors within range of the impact point. Initial estimates of minimum sensor numbers fell in the range 50 to 120.

Mechanical pushbutton switches could sense the deformation of the skin and provide a binary signal, as shown in Figure 2a. The Grayhill 30-2 SPST-NC pushbutton costs approximately $2.70 in lots of 100. The binary signals could be collected via digital Input and Output (I/O) lines, and impact location could be calculated with a simple centroid algorithm.

In many respects, a piezoelectric device can be an ideal impact sensor: inexpensive, sensitive, lightweight, and wide dynamic range. Typical audio range piezoelectric sensors cost approximately $1 each, as shown in Figure 2b. Initial tests with a muRata 7BB-20-6L0 mounted

below the sparring dummy skin indicated that the device could detect impacts to a lateral distance of 4 inches.

A piezoelectric sensor would provide impact amplitude information, thus allowing more accurate detection with fewer devices than the mechanical switches. However, the analog signals would require analog I/O lines, and the host processor would need to process a slightly more intensive algorithm, such as a weighted centroid.

The Analog Devices ADXL362 surface mount, low power MEMS accelerometer costs $7.20 in lots of 250, or it can be procured on a breakout board for $15 each, as shown in Figure 2c.

An accelerometer would provide impact amplitude and direction information, and thus allow more accuracy with fewer devices than the piezoelectric sensors. However, each accelerometer would provide multiple analog (or multi-bit digital) signals which would need to be handled by I/O circuitry. Furthermore, the host processor would be required to compute a more intensive algorithm, taking advantage of the directional information.

B.   Host Processors

Upon an impact event, the host processor must collect all sensor data within a few milliseconds so that a subsequent impact would be detected as a separate event. The sensor data must be stored in a manner which allows for the processing of a quick succession of impacts. And the resulting impact location and time calculations must be reported to the central server in near real time.

For the initial design, an occurrence of multiple impacts which overlap in both location and time was considered a special case of limited value. The design costs of distinguishing between these impacts may be prohibitive and would need to be justified.

There are many suitable low-cost Single Board Computers (SBC) available. Arduino and Raspberry Pi are very low cost and have huge communities for hardware design.

Most of the SBC models do not have enough I/O pins to collect all the sensor signals, but the DigiX, a specialized Arduino Due clone, has 99 I/O pins, which makes it an attractive candidate. Unfortunately, the DigiX is often out of stock and could be difficult to procure.

All of the Arduino models have relatively slow processors. Collecting 120 binary signals and calculating a centroid every 5 to 10 milliseconds could be more than these systems can accomplish, and the more complex algorithms would be even more taxing. Furthermore, no satisfactory I/O hardware for the Arduino could be found.

The Raspberry Pi Model B has a considerably faster processor than the Arduino. Although it provides only approximately 25 General Purpose Input and Output (GPIO) pins, Pridopia makes an extension board with 128 GPIO pins. If a Universal Serial Bus (USB) Wi-Fi adapter is added for wireless communication, then this combination seems to satisfy all the requirements for host processor.

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C. Power

It is possible that a training session would require multiple scenarios with minimal delay between. Recharging batteries between scenarios might be an unacceptable delay. Therefore, the impact reporting system must be able to operate on its own power for more than 2 or 3 hours.

The Raspberry Pi Model B operates on 5 volts direct current at 700 milliamperes supplied through a USB connector. If the power consumption of all auxiliary circuitry is equivalent to the Raspberry PI, then 1,400 milliamperes is the maximum current. A rechargeable USB power supply of 10,000 milliampere-hours would be compact, low cost, and provide more than 7 hours of power. As an example, the New Trent Powerpak 11 provides 11,000 milliampere-hours at a cost of about $40.

D. Initial Design Choices

Initially, it was not known which of the three candidate sensors would perform best. Because of design simplicity, the first prototype incorporated mechanical switches. Each switch was anchored with threaded pipe to the center support post of the sparring dummy, then each switch position was adjusted until it was near the skin.

After the lessons of the mechanical switch-based design, it was decided to pursue two prototypes in parallel: the piezoelectric-based system and the MEMS accelerometer-based system. The piezoelectric-based prototype could be quicker to build. The accelerometer-based prototype could potentially provide more accurate information with fewer sensors.

IV. MECHANICAL SWITCH-BASED SYSTEM

Initially, mechanical switches appeared to provide the simplest, quickest means to build and evaluate the concept of an impact reporting system. The switches were mounted on a steel support shield affixed to the center support post of the sparring dummy. Power and signal wires were routed out the back of the dummy, and a COTS data collection system was employed in order to quickly evaluate the performance. The concept is shown in Figure 3.
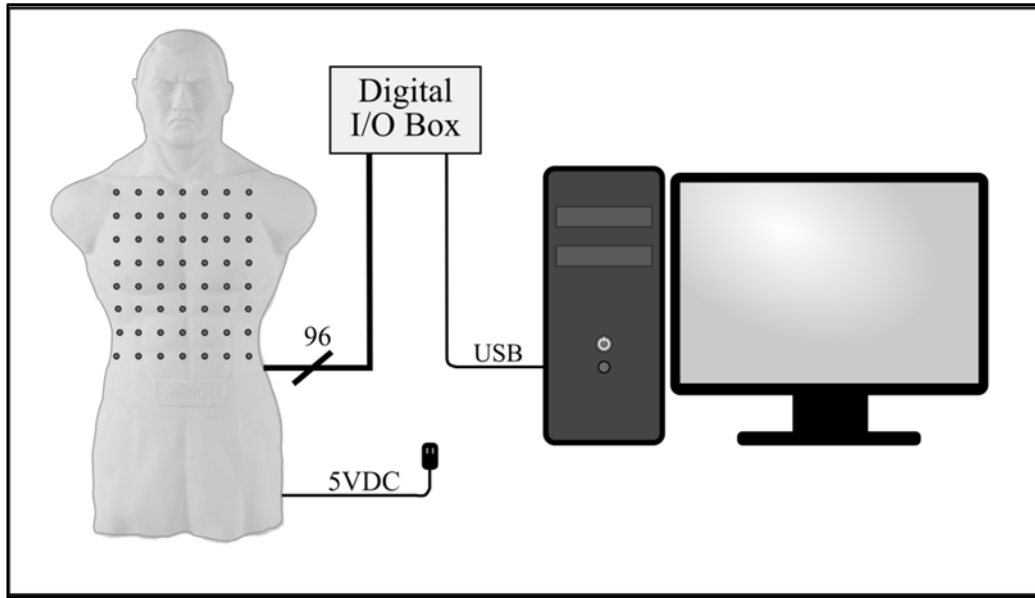
Figure 3. Mechanical Switch-Based Concept

A.   Implementation

The vertical post of the sparring dummy base formed the core support for the foam and plastisol body. The switches were mounted on threaded pipes, affixed to sheet steel, and wrapped around the base post. Sensor posts were attached through evenly space holes drilled into the mounting plate. In all, 56 pushbuttons were arranged in an 8 inches high by 7 inches wide grid pattern. The combination of the position of the mounting hole and the length of the post determined the physical location of the sensor on the dummy surface, as shown in Figure 4. The sensors were adjusted to an approximate uniform depth with respect to the surface and secured with two nuts.
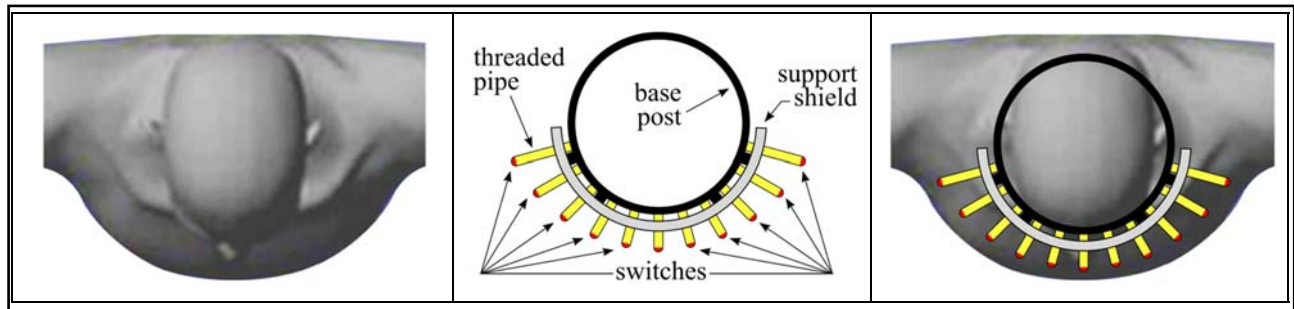
(a.) Dummy, Top View   *(b.) Switches and Supports*   *(c.) Dummy and Switches*

Figure 4. Arrangement of Mechanical Switches

The switches used were Grayhill Series 30, normally closed pushbuttons. Normally closed switches allowed the circuit to be tested prior to data collection. The switches were mounted to the top of a threaded pipe. The pipe length varied according to the amount of material in that particular direction. The switches were held in place by thick heat shrink, and the wires were run through the center of the pipe. Wiring from the switches was routed back

through the center support post to be connected through the digital I/O device to the computer, as shown in Figure 5.
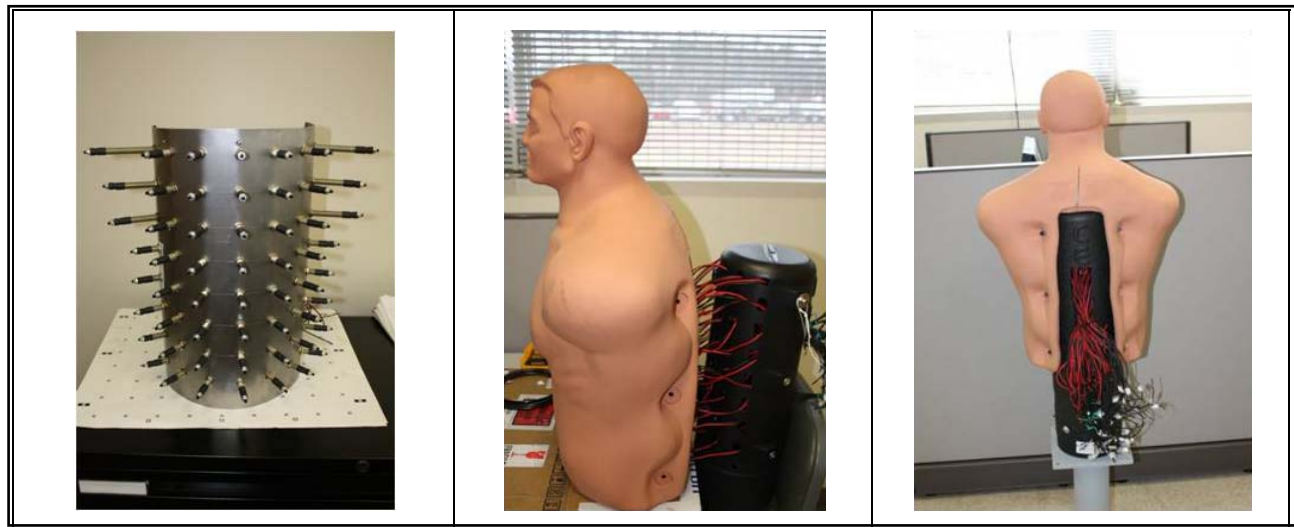
| *(a.) Support Shield and Switches* | *(b.) Wire Routing* | *(c.) Assembled Dummy* |

Figure 5. Mounting of Mechanical Switches

In order to quickly build and evaluate the system, a National Instruments (NI) Digital Input and Output (DIO) interface was used to collect the switch signals and transmit them, via USB, to a computer running a LabView program. An NI USB-6531 was available and used for this test. This device has 24 DIO lines which meant that only a subset of the switches could be active during a single test. The +5 volt direct current reference located on Pin 96 of the internal screw terminal was also used to supply the voltage required for the switch circuit.

A LabView program was written to collect and display the switch signals as well as the calculated location of impact. The program was primarily made of a single unit of code that was repeated for each pushbutton input. When an impact occurred, each routine captured the drop-in signal and latched the signal low. For every pushbutton affected, the corresponding indicator light in the user interface would illuminate, and its position would be added to the list of latched signals. The centroid of all triggered switches would be calculated and marked in the user interface as a bull's-eye pattern.   With the use of the Indicator/Strike button, the user could switch between the two graphical displays, as shown in Figure 6. This feature was also used to determine if the program was performing correctly during development.
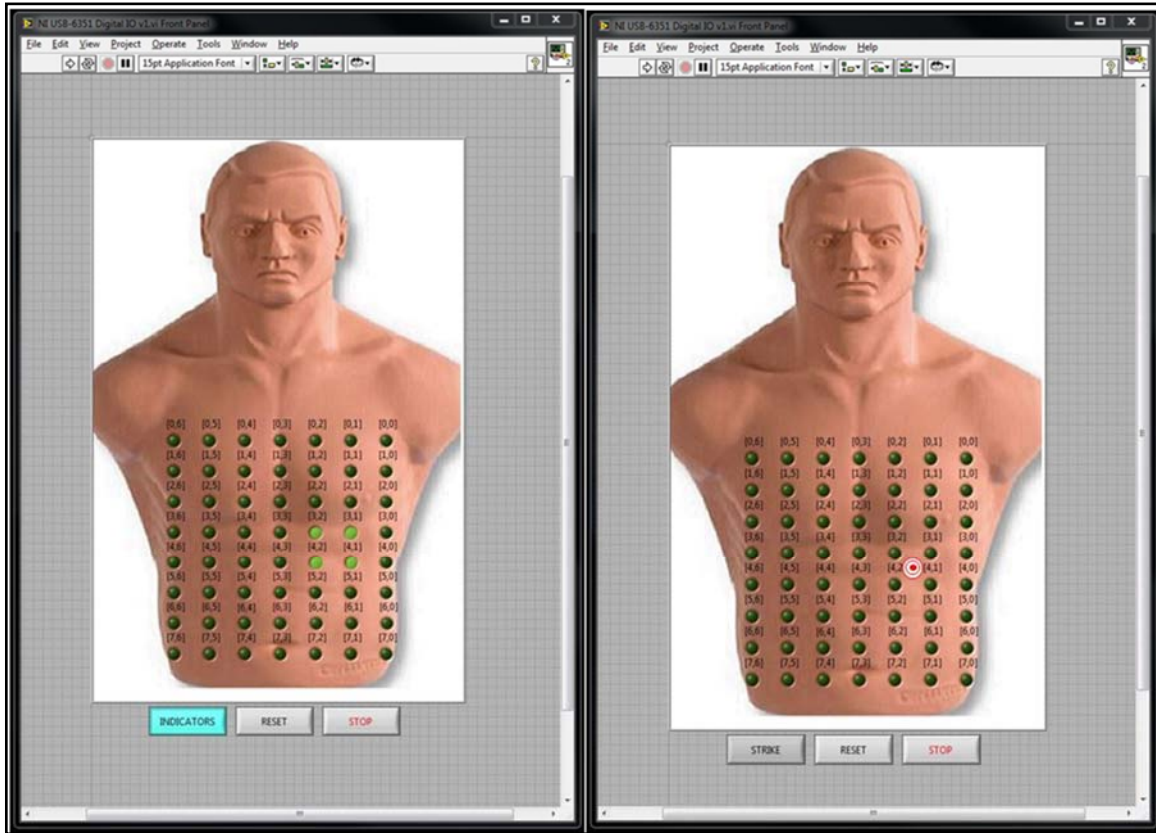
(a.) Triggered Sensors   *(b.) Centroid of Impact*

Figure 6. LabView Interface Display Showing Impact

B.   Results

With this approach, there was a tradeoff between switch survivability and sensitivity. High sensitivity and low survivability near the surface versus low sensitivity but higher survivability further from the surface. It was decided to place the sensors close to the surface for better detection. On lower force impacts, the mechanical switch prototype performed well and provided impact locations to an accuracy of +/- 1 inch. Higher force impacts, on the other hand, caused damage to the switches at the localized impact site.   Indirect hits caused a bending of the joint between the support post and the pushbutton, while impacts directly above the switch destroyed the internal structure of the pushbutton.

The impact damage could be eliminated by redesigning the support post to better protect the pushbutton. In this case, the same inexpensive pushbuttons could be use as long as the amount of depression was limited and the support made more rigid to prevent bending. The best approach would be to enclose the pushbutton inside of the support rod and have a cap with a physical stop. This would allow the sensor to be placed close to the surface for best performance without the risk of damage, as shown in Figure 7.
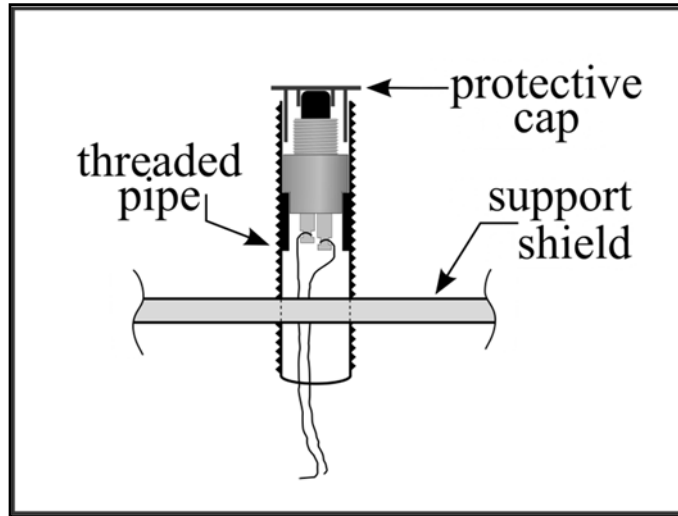
Figure 7. Protective Switch Assembly.

V. PIEZOELECTRIC SENSOR-BASED SYSTEM

The sensitivity and low cost of a piezoelectric device made it an attractive candidate for an impact sensor. These devices have been used for a wide variety of applications from engine combustion sensors to guitar pickups.

A. Initial Sensor Characterization

Initially, basic characterization tests were performed on the model 7BB-20-6L0 piezoelectric sensor because of availability. The sparring dummy used in these initial tests was a different model than the Century BOB XL specified in the final design, but the plastisol skin and foam body had similar properties. The sensor was placed in the foam just under a flap of skin, and the skin flap was held closed. Impacts were simulated by striking the dummy with a plastic head hammer. The resulting electrical response was captured on a digital oscilloscope.

Nominal impact data were not available at the time; therefore, characterization was performed with a range of hammer blows which were estimated to bracket the expected impact strengths.

The first series of tests were performed by striking with the hammer as if driving a finishing nail, that is, not very hard. At each lateral distance from the sensor, the dummy was struck multiple times and each peak voltage recorded, as shown in Table 1. The second sequence involved striking the dummy considerably harder, with results listed in Table 2.

Table 1. Sensor Response to Light Hammer Blows

Lateral Distance to Impact (inch)	Sensor Peak Response (V)
0	7.1, 8.9, 5.5, 6.5
2 (above)	3.5, 3.1, 3.7
4 (above)	1.3, 1.1, 1.4

Table 2. Sensor Response to Vigorous Hammer Blows

Lateral Distance to Impact (inch)	Sensor Peak Response (V)
0	8.6, 20.2 (broken wire)
2 (above)	5.4, 5.4 (-15V spike)
4 (above)	1.8, 1.4
2 (to left)	3.8, 5.4, 4.2
4 (to left)	1.8, 2.3, 4.0
6 (to left)	2.4, 2.0, 1.3

These initial tests were not calibrated. They simply served to indicate whether these sensors could produce useful signals in the desired environment. The conclusion was that the piezoelectric sensor performance was promising enough to pursue further characterization.

The initial tests also suggested a starting point for design with these sensors. A sensor within 4 inches of an impact consistently produced a signal of at least 1 volt. This implied that in an array of piezoelectric devices uniformly spaced 4 inches apart, impact location could be determined by comparing all sensor signals to 1 volt.

The piezoelectric sensors provided a wide dynamic range analog signal. Designing a low-cost data collection system with dozens of analog acquisition channels and the necessary post-processing might involve undesired compromises. In order to lessen the demands on I/O hardware, the sensors were initially interfaced in a binary digital manner. Their signals were filtered, thresholded, and presented to a DIO interface.

A simple limiting amplifier with floating input was designed to interface the piezoelectric sensors to the DIO system. The adjustable threshold level was originally fixed at 1 volt. Overvoltage and undervoltage protection were provided by a Zener diode, and the output signal was limited to Transistor-Transistor Logic (TTL) levels. With minor modification, the amplifier design in Figure 8 would also be capable of producing output levels of other logic families.
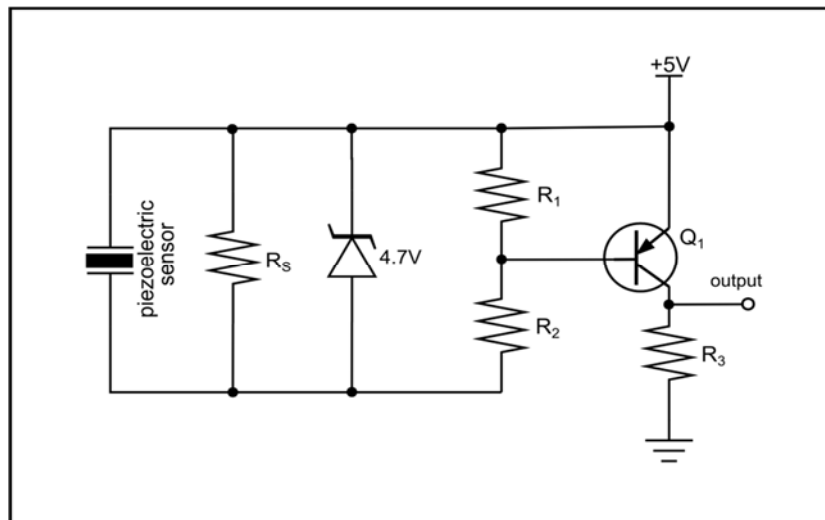

Figure 8. Initial Limiting Amplifier Schematic

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The ability of the amplifier to produce TTL level output was verified by inserting the sensor into the dummy and striking it several times with a plastic head hammer. The oscilloscope screen capture of a typical event is displayed in Figure 9. Even a hammer blow 4 inches away from the sensor produced a TTL pulse.
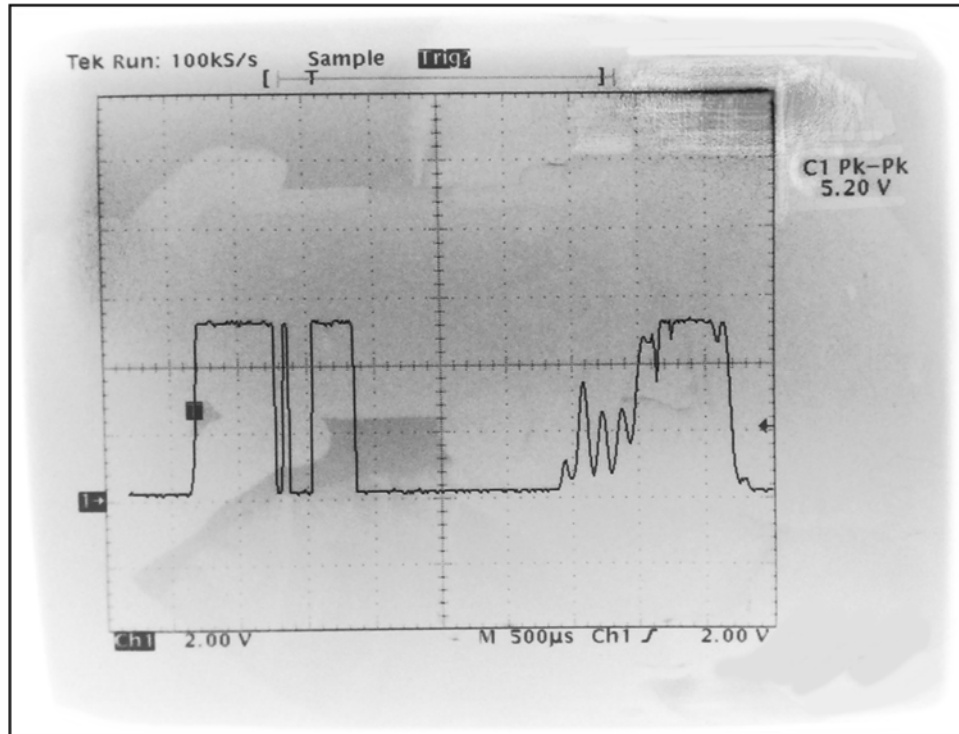

Figure 9. Typical Output From Limiting Amplifier

In order to gauge the durability of the piezoelectric devices to repeated impacts, a more vigorous test was designed. The sensor was sandwiched between a layer of plastisol skin and a 1.5-inch layer of white packing foam sitting on a solid floor. And the sensor location was struck very hard several times with a handheld sledgehammer. The sensor signal was monitored on a digital oscilloscope.

The sensor responded well to several hammer blows, producing peak voltages of 20 to 30 volts, but the sensor failed eventually. An examination showed that both connecting wires had been broken, and the sensor was cracked.

B. Encapsulated Piezoelectric Design

The piezoelectric sensor must be able to survive the energy of repeated impact and still produce meaningful signals. During initial characterization, it became apparent that the piezoelectric sensor could be shattered or the wires broken by a vigorous impact. It was proposed that a protective shell might be constructed which could limit sensor damage while maintaining performance.

To test this approach, a piezoelectric sensor was mounted in a short section of polyvinyl chloride (PVC) pipe and sealed with two end caps. The signal wire exited with strain relief through a hole in an end cap, as shown in Figure 10.
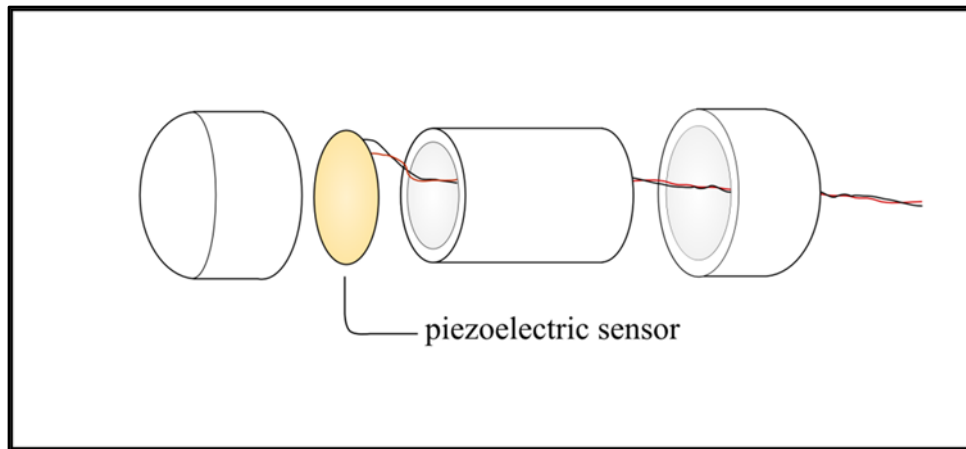
Figure 10. First Version of Encapsulated Sensor

This design was tested by enclosing it in foam and striking it 100 times with a handheld sledgehammer while observing the electrical response on an oscilloscope. The encapsulated sensor was placed in a hollow in the upper of two foam blocks, and the foam blocks were stacked on a hard surface, as shown in Figure 11.

Figure 11. Configuration for Torture Testing of Encapsulated Sensor

During the first 60 strikes, the upper layer of foam disintegrated, and the final 40 strikes were applied directly to the PVC shell, which had been driven into the lower foam block.

The sensor response to every impact was adequate, and the wiring did not fail during the test. The PVC encapsulation had protected the sensor. However, subsequent testing revealed that the so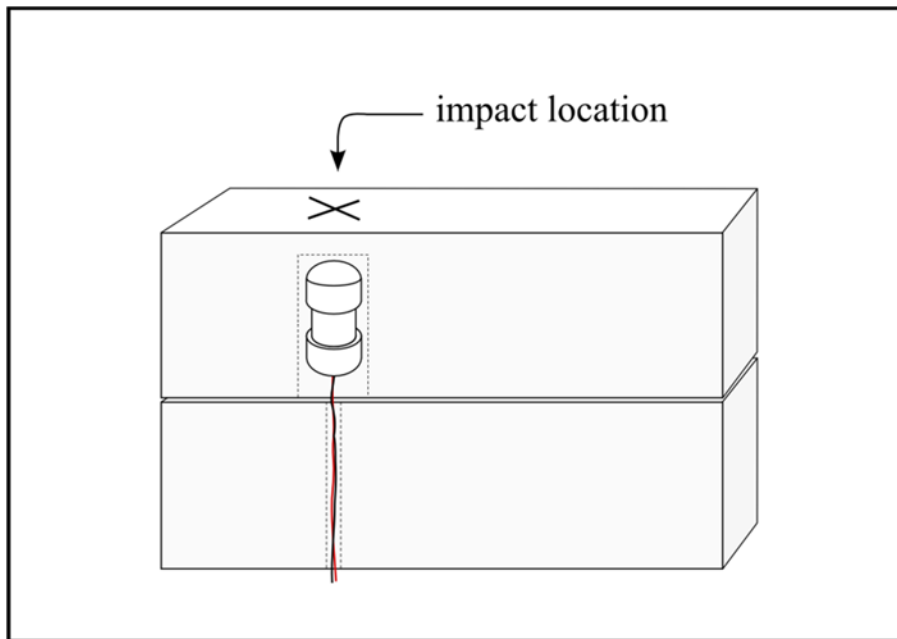lder connections to the sensor would eventually became unreliable. Therefore, another configuration was designed with strain relief on the side of the protective shell, as shown in Figure 12.

The addition of protective foam cushioned the sensor during violent impacts. Moving the wire exit hole to the side of the PVC pipe reduced the length and mass of free hanging wires attached to the sensor. Note that the end caps were trimmed to avoid encroaching on the wire exit hole.
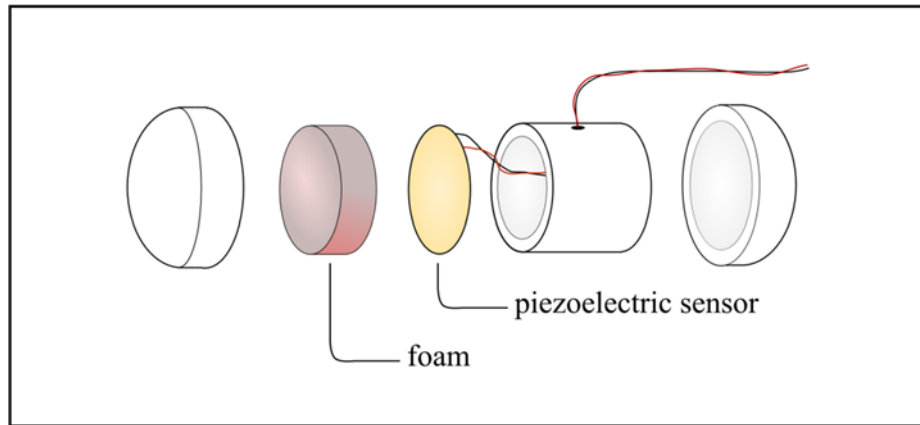

Figure 12. Improved Design of Encapsulated Sensor

The improved design was characterized by mounting it in the target sparring dummy. High-speed blows by a plastic head hammer emulated the desired impacts and peak voltages were read from the digital oscilloscope. These were tabulated, as shown in Table 3, as peak response versus lateral distance from impact. The improved design protected the sensor while allowing for adequate performance.

Table 3. Response of Sensor in Improved Encapsulation

Lateral Distance To Impact (inch)	Sensor Peak Response (V)
0	36.8, 29.4, 32.2, 34.6, 40.2, 37.0, 40.2
2 (above)	6.0, 6.6, -10.4, 6.2, -8.2, 8.0, -10.2, 8.6, -10.6, 9.6, -8.4
2 (to side)	13.2, -5.8, 14.8, -5.4, 22.0, -7.4, 12.2, -5.2, 9.6, -6.4, 14.4, -7.2, 14.4, -6.2, 13.4, -7.0
4 (above)	7.8, -8.4, 7.2, -10.0, 7.4, -6.8, 6.4, -9.8, 7.4, -7.0
4 (to side)	5.8, -5.0, 7.0, -3.8, 7.0, -4.0, 8.6, -5.2, 1.6, -2.8, 1.6, -2.6, 6.6, -5.4, 4.8, -3.2

C.   Improved Interface Circuit

Cost and power limitations of the host processor drove the selection of the data acquisition system. It would have been desirable to collect all sensor signals and use an algorithm, such as a weighted centroid, to calculate impact location. However, such an approach

did not seem possible given the required number of sensors and speed of the embedded processor. Instead, a discrete (TTL) data acquisition system was chosen, necessitating an interface circuit between each sensor and its data acquisition channel.

The goals of the sensor interface circuit were to protect against over and under voltages, respond only to desired signals, and deliver an output compatible with the DIO system. Desirable signals were those produced by sensors within a set distance of a local impact.

During testing, hammer strikes within 4 inches of the sensor location reliably produced sensor signals of 5 volts or greater. Therefore, a static voltage threshold of 5 volts was chosen. This determined the values of the voltage divider resistors.

Examination of signals during testing also showed that undesirable high frequency oscillations and transients of 100 microseconds or less duration were present. In order to reject these, a filter capacitor was added to the original limiting amplifier design, as shown in Figure 13. The value of the filter capacitor was adjusted until the output of the amplifier discriminated between the desirable and undesirable signals.
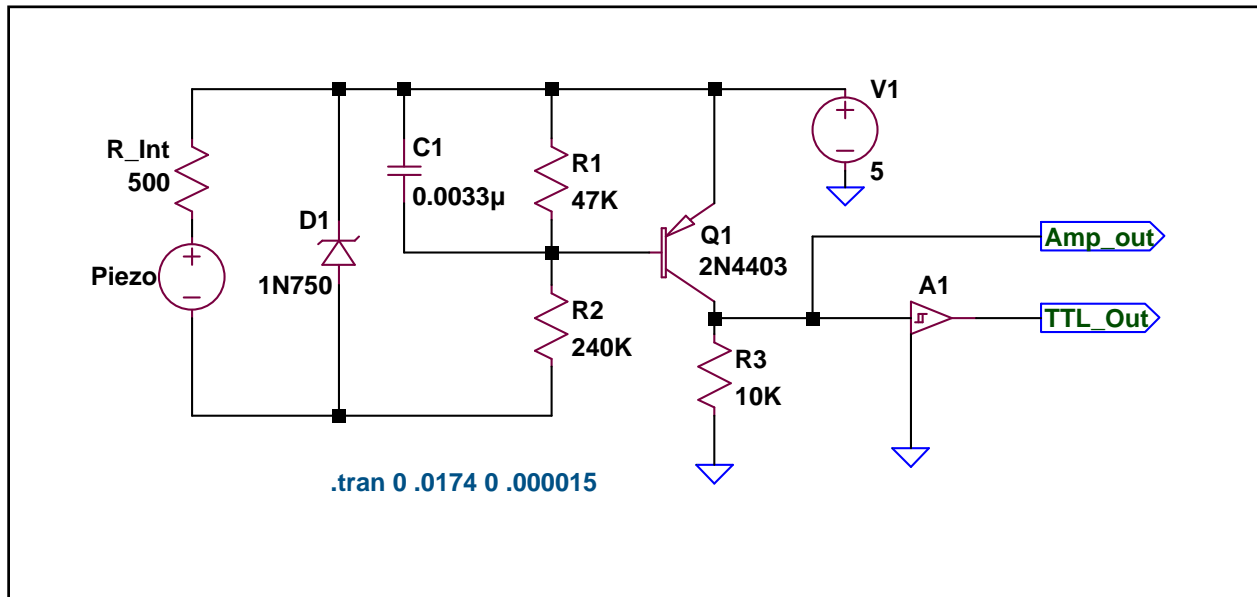

Figure 13. Improved Interface Circuit Schematic

The schematic in Figure 13 was designed to run in a simulator (LT Spice), so there were several deviations from the actual design circuit. First, R_Int represented the internal resistance of the piezoelectric device. It was necessary to specify this in order to accurately produce the sensor voltage and current. Second, the Schmitt buffer, A1, was not part of the interface circuit but represented the input stage of the data acquisition system, allowing the simulation to calculate and plot the response of the data acquisition system.

In order to characterize the response of the interface circuit, a complex waveform test signal was constructed to provide the Spice simulation with a set of exemplary piezoelectric sensor signals. Signal waveforms and levels were chosen by measuring unloaded response of a piezoelectric sensor mounted in the target dummy.

The five sections of the example sensor test signal are shown in Table 4 and plotted in Figure 14. The first three sections include spikes of 150 microseconds duration to test for rejection of signals shorter than an actual impact. Section 1 tests the overvoltage limiting, Section 2 represents a nominal impact signal near the edge of sensitivity, and Section 3 represents a nominal impact signal just beyond the edge of sensitivity. Section 4 tests the ability to reject oscillatory signals, and Section 5 represents an impact signal of the shortest acceptable duration and lowest acceptable amplitude. Figure 14 shows that the interface circuit produces the proper response to each of the test signal sections.

Table 4. Example Piezoelectric Sensor Test Signal

Waveform Time Begin/End (ms)	Description
0/3	12V pulse with 12V spikes
4/7	5.5V pulse with 5.5V spikes
8/11	4.5V pulse with 4.5V spikes
12/15	3V peak oscillation at 6 KHz
16/17	short 5.5V pulse
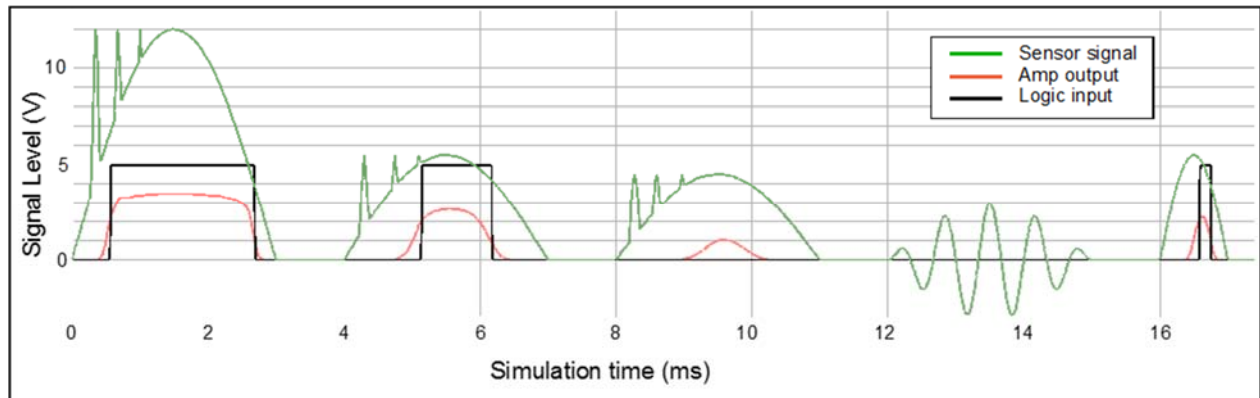
Figure 14. Simulated Response of Improved Interface Circuit

D. System Design

The final design for the piezoelectric sensor-based system will consist of all the components necessary to convert a sparring dummy into a target with wireless impact reporting: encapsulated sensors, interface circuitry, DIO board, host processor, and power supply, as shown in Figure 15b. Mounting hardware, wiring connections, and programming the host processor will be nearly identical for every dummy. The exception is that each dummy will have its own unique Identification (ID) in order for the central server to distinguish between targets.

(a.) Sensor Placement   *(b.) System Concept*

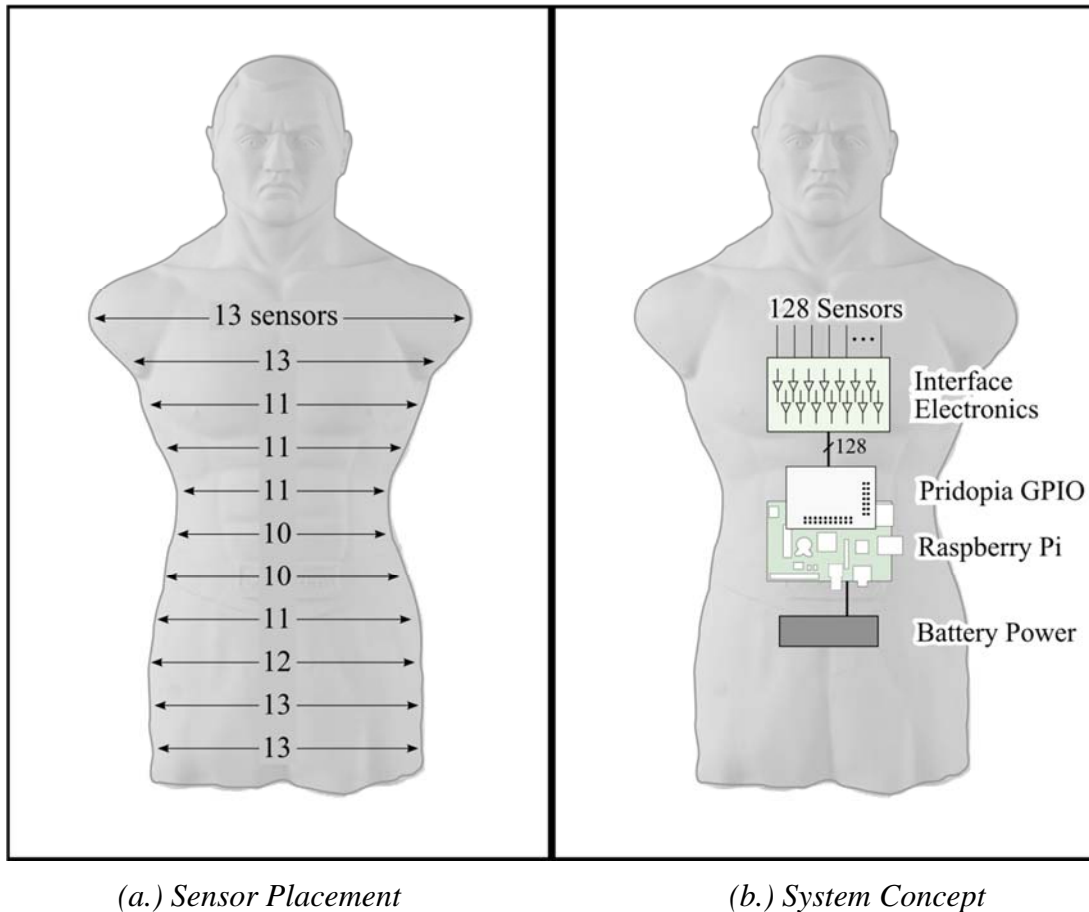*Figure 15. Piezoelectric Sensor-Based System*

The piezoelectric sensors in the immediate vicinity of an impact will produce a signal which will be filtered, converted by the interface circuitry, and fed to the Pridopia DIO board. The Raspberry Pi processor will poll the DIO lines and collect the signals of all reporting sensors. Using the calibrated location values of the sensors, the actual impact location will be calculated. Then, the host processor will report impact location and time to the central server.

In order to specify the precise number of signal channels for the host processor and interface circuitry, the number and layout of piezoelectric sensors was calculated by measuring the sparring dummy. Based on an assumption that sensors would be spaced 2 inches apart in each dimension, the width of the front surface of the dummy was measured at each of 11 evenly spaced vertical locations. The total number of sensors specified in this layout was 128, as shown in Figure 15a.

Although the described layout did not cover the full exterior of the sparring dummy, this prototype would provide a proof of the concept as well as practical data on such issues as durability and precision of impact location.

Sensors would be installed through slits cut in the inside of the body foam and fixed in place by glue. Although sensor placement would not be precisely evenly spaced, calibration of the properly weighted location algorithm should provide accuracy. Results of a series of

controlled impacts would provide the calibration factors, and a location algorithm, such as a weighted centroid, should suffice.

VI. MICRO-ELECTROMECHANICAL SYSTEM ACCELEROMETER-BASED SYSTEM

The Analog Devices ADXL362 is a low power, 3-axis MEMS accelerometer with onboard Analog-to-Digital Converter (ADC) and digital storage buffer. Capture of event data can be triggered by internal measure of acceleration relative to a programmable threshold. Because the accelerometer can capture event data independently, the host processor is relieved of monitoring events in real time.

Without in-house surface mount capability, it was decided to purchase the ADXL362 mounted on a SparkFun SEN11446 breakout board. While this increased the sensor cost to $12 each, it also reduced the characterization time.

A. Accelerometer Test Interface

The ADXL362 communicates with a host processor via Serial Peripheral Interface (SPI) bus with a clock rate of 1 to 5 megahertz. In order to test and characterize the device, a Nano River Technologies (NRT) TigerBoard USB I/O interface was connected to a desktop computer running Windows 7 and the necessary driver software. The accelerometer breakout board was connected to the SPI interface of the TigerBoard, as shown in Figure 16. Various programs were written in C to communicate with and exercise the ADXL362.
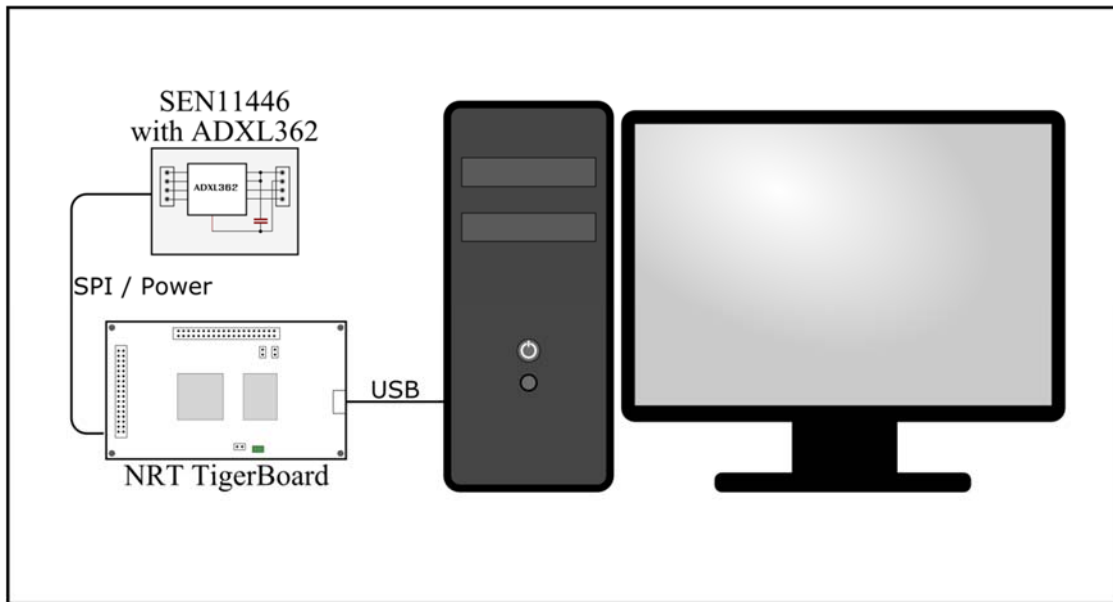

Figure 16. Accelerometer Test Configuration

B. Accelerometer Characterization

The ADXL362 can measure and store acceleration readings for the X-, Y-, and Z-axes and the internal temperature of the device, which can be used to adjust for temperature

drift in the acceleration readings. It was decided to disable the temperature readings to save memory space for this application. The data are stored in the chips First-In, First-Out (FIFO) buffer. The FIFO can hold up to a maximum of 512 readings at 16-bit resolution. There is an option on the chip to store only 8-bit data for each axis to increase the number of stored readings. For this application, 16-bit acceleration data were used to allow for greater accuracy in calculating impact point locations. This meant that only 170 sets of X, Y, and Z data could be stored before buffer rollover.

The accelerometer can generate an interrupt based on both activity and inactivity events. Inactivity event interrupts can be used to reduce power consumption by switching the chip into sleep mode. Since there is a significant delay in waking the chip from sleep mode, it was decided to interrupt on activity events only.

The ADXL362 indicated the occurrence of an impact by generating an activity interrupt when the instantaneous acceleration exceeded a set threshold, relative to a preset reference. For laboratory testing, the reference was determined by an initial gravity reading done with the chip at rest and the axes oriented as tested. During operation, the reference acceleration vector was subtracted from the measured acceleration, and the resulting magnitude compared to the threshold at the chip level. An interrupt was generated when the following condition was met:

$$\|Acceleration - Reference\| > Threshold$$

This option was used to isolate the impact acceleration values from the stationary readings.

While waiting for an impact event interrupt, the ADXL362 records data in the FIFO continually.   On each successive write cycle, all data in the FIFO are shifted to the next higher address, and the new data are written to address 0. Data at the highest address are shifted from the buffer and lost. This process continues until an interrupt occurs. On interrupt, data are frozen in a specified range of addresses that can be designed to allow capture of data surrounding the event of interest. Following the interrupt, the chip continues to write data to the remaining buffer locations, which function as a smaller version of the FIFO. The chip remains in this state until the saved data are read.

C.   System Design

The accelerometer-based impact detection system is envisioned, as shown in Figure 17, with internal battery power supply, custom SPI bus control board, and a Raspberry Pi as the host processor. Accelerometers would communicate with the host processor, through the SPI board.
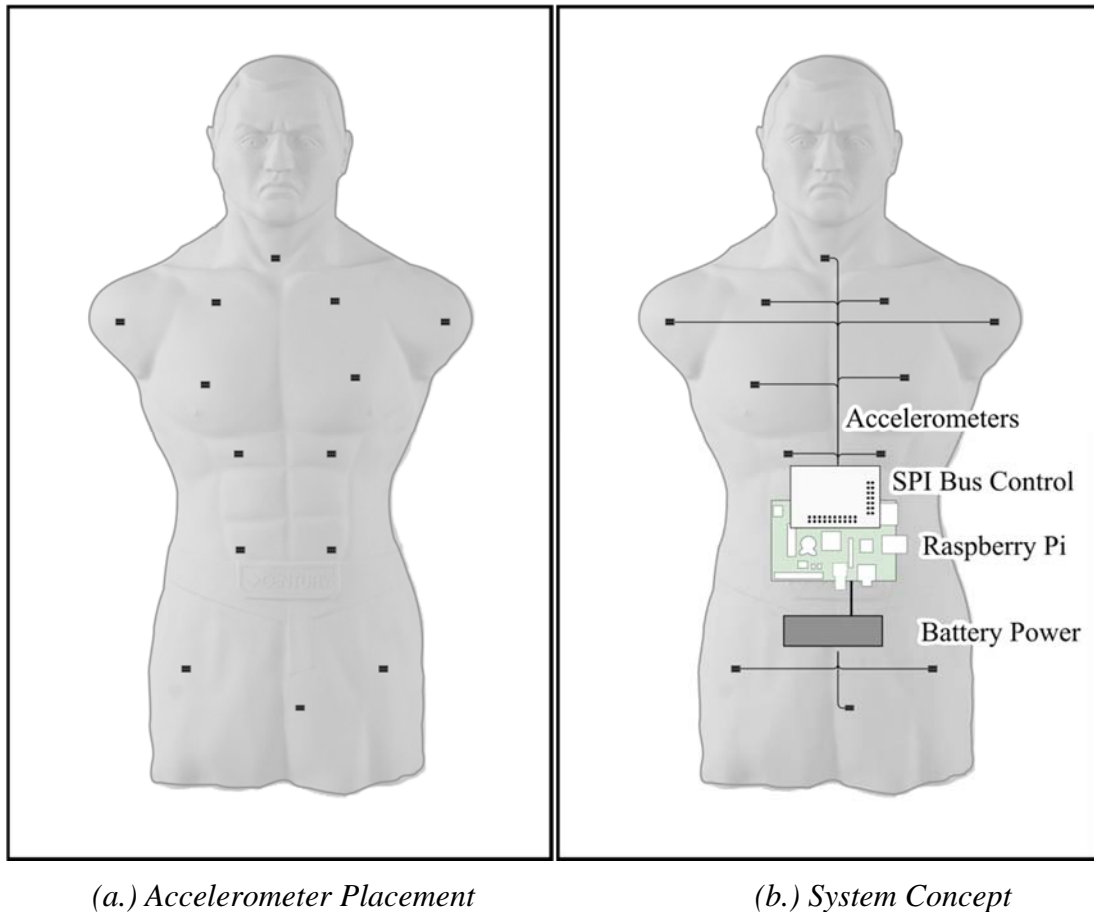
(a.) Accelerometer Placement   *(b.) System Concept*

Figure 17. MEMS Accelerometer-Based System

For the purpose of sensing an impact, each accelerometer would perform as a quasi-independent data collection system—detecting an impact, collecting acceleration data, and notifying the host processor by interrupt signal. Upon receiving an interrupt signal, the host processor would collect all data from the affected accelerometers and analyze the impact event. Impact location and time would then be reported to the central server.

Communication between the host processor and accelerometers is accomplished over two separate busses: the SPI bus and the accelerometer interrupt lines. The SPI bus handles all configuration, command, and acceleration data. The accelerometer interrupt lines are mapped to the host processor and trigger the collection of data for an impact event.

Although the data lines of the SPI bus are shared among all devices, each slave device (accelerometer) must receive an individual chip select signal prior to receiving any command. This would be implemented on a custom SPI bus control board, as shown in Figure 17b. The bus control board would provide an address decoder to drive all the chip select lines as well as current drivers for the data lines.

Ideally, the accelerometer interrupt lines would be mapped to GPIO pins on the Raspberry Pi. However, if the number of sensors grows beyond that capability, then the SPI bus control board would be assigned the additional task of address encoder for all the sensor interrupt

lines. The address encoder would not only encode the address of each interrupt, it would load each interrupt address into a buffer and notify the processor via GPIO line.

An impact event would cause each local accelerometer to self-trigger and collect data. In the example of Figure 18, three accelerometers sensed the event. Interrupt signals prompted the processor to collect the acceleration data from all three sensors. Following this, the processor calculated the time and location of the impact and reported that to the server.
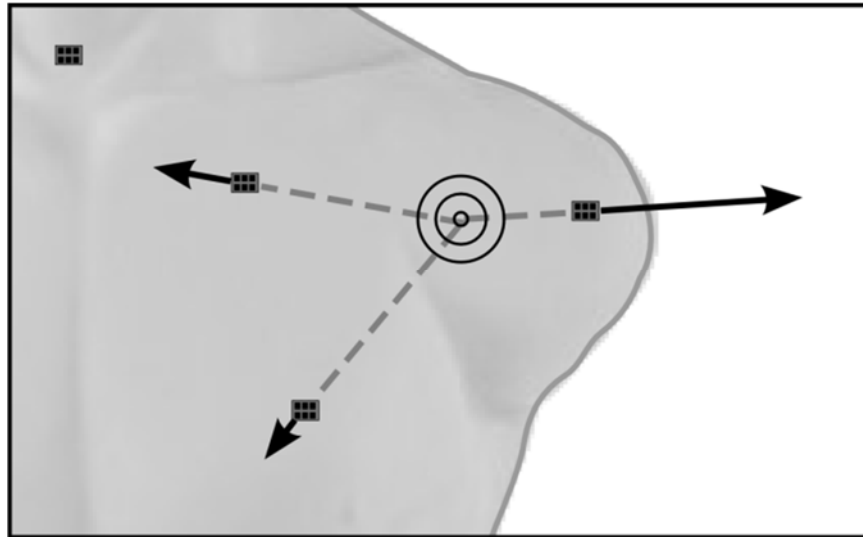

Figure 18. Directional Location of Impact on Shoulder

The impact locations would be triangulated using the lateral acceleration vector of each sensor, as shown in Figure 18. In the case where nonuniformity of the dummy causes discrepancy in the vectors, accuracy of the estimate would be increased by weighting each vector according to the magnitude of acceleration at the associated sensor.

VII. CONCLUSIONS AND RECOMMENDATIONS

This report has outlined three designs of a standalone, sensor equipped sparring dummy capable of detecting blunt force impact timing and location. Given budget and time constraints, only the sensors and crude laboratory prototypes were evaluated. Within the scope of these experiments, each of the designs performed as expected.

For these experiments, impact force was estimated, and measurements of actual impact from the blunt projectile were not available. Because of this, all designs were subjected to a wide range of impacts in an attempt to identify weaknesses and points of failure. Calibrated measurements of actual, indicative impacts would necessarily affect the number, placement, and measurement of sensors; however, it was believed that each of the three designs would be adaptable to the requirements. A final design choice would most likely be driven by cost and reliability considerations.

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

μ	micro
Amp	Ampere
ADC	Analog-to-Digital Converter
Ch	Channel
COTS	Commercial Off-The Shelf
DIO	Digital Input Output
FIFO	First-In, First-Out
GPIO	General Purpose Input and Output
ID	Identification
I/O	Input and Output
KHz	kilohertz
kS/s	kilosamples per second
MEMS	Micro-ElectroMechanical System
ms	millisecond
NI	National Instruments
NRT	Nano River Technologies
Pk-Pk	Peak-to-Peak
PVC	polyvinyl chloride
SBC	Single Board Computer
SPI	Serial Peripheral Interface
TTL	Transistor-Transistor Logic
USB	Universal Serial Bus
V	volt
VDC	volts direct current